Chapter 2
Seismic Background and Context

DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT

Brightwater Regional Wastewater Treatment System

Chapter 2
Seismic Background and Context

This Supplemental EIS has been prepared to address new information on the Southern Whidbey Island Fault (SWIF) that has become available since the publication of the Final EIS in 2003. The research finding regarding the SWIF that is most significant for the proposed Brightwater Regional Wastewater Treatment System is that an active strand of the SWIF (Lineament 4) was discovered beneath the northeast corner of the proposed Route 9 site for the Brightwater Treatment Plant. This chapter provides information about the study of earthquakes to help readers understand the discussion of impacts later in the document. It includes a discussion of methodologies used to locate earthquake faults; seismic characteristics of the Puget Sound region, including the SWIF; seismic studies that have been conducted on and near the Route 9 site; and uncertainties about seismic features on the Route 9 site.

2.1 Are Earthquake Faults Present on the Route 9 Site?

The SWIF is a northwest trending, active fault that was first documented on Whidbey Island where the fault has been found to have moved as recently as about 3,000 years ago. Geologically, faults are considered to be active if they have moved in the Holocene Epoch, which in the central Puget Sound area corresponds to movement within about the past 16,000 years.

Prior to about 2003, there were scant data indicating that the SWIF extended onto the mainland. Recently, the U.S. Geological Survey (USGS) has conducted studies using multiple lines of investigation, including surface trenching. These recent studies have established that the SWIF does extend onto the mainland and that an active strand of the fault, identified as Lineament 4 (Blakely et al., 2004), intercepts the northern portion of the Route 9 site. Trenching of Lineament 4 on the Route 9 site in September 2004 indicated that at least two and possibly three earthquakes occurred on this fault strand. The oldest earthquake occurred about 16,000 to 12,000 years ago and produced 3 feet (1 meter) or more of uplifting or bending of the ground surface; the youngest occurred no more than about 3,000 years ago with less than 1 foot (0.3 meter) of deformation.

While there are no other confirmed faults underlying the Route 9 site, in the fall of 2004 the USGS reexamined existing scientific data (aeromagnetic data) for the site and identified a lineament (Lineament X in Appendix A) that may intercept the southern portion of the Route 9 site. The presence of Lineament X at the Route 9 site could not be confirmed in the existing regional LiDAR data, which is another scientific method used to identify potential faults. (LiDAR is the acronym for light detection and ranging imagery.) The LiDAR data, however, could not necessarily preclude the potential extension of Lineament X beneath the Route 9 plant site because of past grading of the site and the resolution of the LiDAR data.

Both the design of the treatment plant and the analysis of impacts in this Supplemental EIS consider the confirmed presence of an active fault at Lineament 4 and the potential presence of a fault at Lineament X. Both structural and nonstructural components of the treatment plant facilities are being designed to resist the forces associated with predicted levels of ground shaking. These levels consider the potential occurrence of earthquakes on Lineaments 4 and X as well as on other earthquake sources in the region, in accordance with accepted seismic design standards (see Chapter 3). This Supplemental EIS evaluates the worst-case environmental impacts that could result if a rupture were to occur on either of these possible faults or on a hypothetical fault elsewhere on the Route 9 site.

2.2 How Do Researchers Locate Earthquake Faults?

Researchers use several different methodologies to determine where an earthquake fault may be located. Each methodology provides researchers with different types of information, which then must be interpreted to infer whether features consistent with an earthquake fault are likely to be present. The methodologies have varying levels of confidence. When data from several different methodologies are used and compared, the presence or absence of a fault can be inferred with a greater degree of confidence than if only one methodology were used.

The methodologies described below have been used to determine the potential presence of earthquake faults that could affect the Brightwater Treatment Plant site. Specific studies are described in more detail later in this chapter.

2.2.1 Aeromagnetic and Ground Magnetic Surveys

An aeromagnetic survey uses a magnetometer towed behind an aircraft to measure the intensity of the earth’s magnetic field. The differences between actual measurements and theoretical values indicate anomalies in the magnetic field, which, in turn, represent contrasts in the type, thickness, or depth of rock. Aligned sharp contrasts in the data, identified or mapped as “lineaments,” may suggest the presence of a subsurface earthquake fault. A mapped aeromagnetic lineament represents the contrast of subsurface properties occurring at depth. As such, the surface projection of the lineament may coincide or may be offset from aeromagnetic evidence of fault movement.

A ground magnetic survey is equivalent to an aeromagnetic survey except that it is performed at the ground surface. Ground magnetic measurements are usually made with portable instruments at regular intervals along more or less straight and parallel lines that cover the survey area. Often the interval between measurement locations (stations) along the lines is less than the spacing between the lines. The type of equipment and line spacing used during ground magnetic surveys are such that the resulting data provide an indication of anomalies closer to the ground surface than do data from an aeromagnetic survey. Like the aeromagnetic survey, differences occur between a lineament location interpreted from the ground magnetic data and the surface projection, although the degree of offset could be less.

All lineaments interpreted from the aeromagnetic and ground magnetic data are not necessarily caused by earthquake faults; additional lines of evidence are needed to determine if identified lineaments are likely related to a fault. Furthermore, aeromagnetic and ground magnetic data do not convey information that can differentiate active faults from inactive faults.

2.2.2 LiDAR Surveys

LiDAR—light detection and ranging imagery—surveys use laser equipment aboard an airplane to measure ground surface elevations. The data can be used to infer locations where linear traces of elevation shifts or offsets could be suggestive of a fault. LiDAR indicates the location of a potential fault more precisely than does an aeromagnetic survey because it detects differential displacement at the ground surface. When used in conjunction with aeromagnetic or ground magnetic surveys, it can help scientists map the location of a suspected fault with a greater level of confidence.

All lineaments interpreted from the LiDAR data are not necessarily caused by earthquake faults. Additional lines of evidence are needed to determine if identified lineaments are likely related to a fault.

2.2.3 Seismic Refraction Surveys

In a seismic refraction survey, very small vibrations, referred to as seismic waves, are generated at the ground surface by striking or vibrating the ground. The waves travel down through the soil, then along discontinuities or zones of contrasting velocities or differing types of materials. Subsequently, the waves travel back to the ground surface where they are detected by geophones or sensing devices placed at the ground surface. The travel time of the waves through soil or rock can be used to identify discontinuities or contrasts in geologic materials that may suggest the presence of a fault.

All anomalies interpreted from the seismic refraction data are not necessarily caused by earthquake faults; additional lines of evidence are needed to determine if identified anomalies are likely related to a fault. Furthermore, data from seismic refraction surveys do not convey information that can differentiate active faults from inactive faults.

2.2.4 Soil Samples

Soil samples can be retrieved by drilling borings from just a few feet to several hundred feet deep. Boring logs are prepared to provide a written record of the subsurface conditions encountered during field investigations; the logs graphically illustrate the different geologic layers encountered in the borings. Researchers can examine the soil samples for evidence that could suggest the presence of a fault, such as fractures, zones of disturbance, and locations where similar soil units or marker beds are encountered at differing elevations in adjacent borings.

2.2.5 Geologic Reconnaissance

In a geologic reconnaissance, geologists can use the findings from aeromagnetic and LiDAR surveys to identify areas on a site where changes in ground elevation may indicate an underlying fault. They then can make direct observations of surface features and use the results to select locations for excavating trenches to expose shallow geologic features as part of the procedure to evaluate the potential presence of fault traces.

2.2.6 Trench Excavations

When analysis of the data acquired by the methodologies described above strongly suggests that a fault may be present in a particular location and when there is a need or a desire to confirm the presence or absence of a fault, geologists may excavate a trench across the identified feature to expose the subsurface soil layers for evidence of fault movement, such as deformed, disturbed, or offset soil beds. Trenches generally are limited to a depth of 15 to 20 feet below the ground surface.

2.3 How Are Earthquakes Measured?

The relative strength of an earthquake is quantified by its magnitude (M), which is a measure of the energy released by the earthquake. Two types of magnitude scales are commonly used, one based on measurements recorded by seismographs (Richter scale) and one based on the area of a fault plane that is involved in the earthquake (Moment scale). The different scales are used for different purposes. The Richter scale is the most commonly known method of measuring the magnitude, but the Moment scale is more meaningful for use in engineering design. The two magnitude scales yield approximately the same value for earthquakes up to about M 7.0. This Supplemental EIS will follow the USGS convention (USGS, 2004) and report magnitude to the nearest tenth without referencing the scale (for example, M 6.8, M 7.0, and so forth).

2.4 What Are the Geologic Characteristics of the Puget Sound Region?

The geology of the Puget Sound region is described in Chapter 4 of the Brightwater Final EIS. The Brightwater project area lies within the central part of the Puget Lowland, which is bounded on the east by the Cascade Range and on the west by the Olympic Mountains.

The Puget Lowland is underlain at depth by volcanic and sedimentary bedrock deposited more than 2 million years ago. It is filled to the present-day land surface with glacial and nonglacial sediments deposited since then. During this time, the Puget Sound region has undergone at least six periods of continental glaciation. During glacial advances, meltwater and ice scoured the underlying soil and rock, reworking and entraining sediment and carrying it south. As the glaciers retreated, they deposited their sediment load over the uncovered landscape. Between glaciations, erosional and depositional processes worked on the landscape much as they do today.

The most recent glacial sediments in the Puget Lowland were deposited between 18,000 and 16,000 years ago. Erosion between glacial cycles produced a setting in which these sediments can lie directly on any of the older glacial or nonglacial sediments. The most recent glacial sediments can be entirely absent where they were eroded or never deposited.

2.5 What Are the Seismic Characteristics of the Puget Sound Region?

The Puget Lowland has experienced earthquakes in the past and is expected to experience them in the future. Most of these earthquakes are the direct result of plate tectonics. The Puget Lowland is located near the edge of a region where two tectonic plates collide and one plate overrides the other. To the west, the Juan de Fuca plate, which lies off the coast of North America, is being pushed eastward, causing it to collide with and dive under the North American plate, which comprises the Pacific Northwest (Figure 2-1). Over millions of years, the collision of these two plates has created the mountains in the Olympic Range and is responsible for the volcanoes in the Cascade Range.

As the plates slide and bend, they produce earthquakes. Earthquakes affecting the Puget Sound region typically occur within one of three source zones related to the colliding plates—the Cascadia Subduction Zone, the Intraslab or Benioff Zone, or the Crustal Zone. Earthquakes as large as M 9.0 have occurred. However, most earthquakes are much smaller; usually they are not felt by residents in the area and cause little to no damage. Earthquakes in the Puget Sound region from 1900 to the present are shown on Figure 2-2; this figure also indicates the depth and estimated magnitude of each earthquake. As indicated in Figure 2-2, no earthquakes have occurred during the past 100 years within about 4.5 miles (7 km) of the Route 9 treatment plant site.

2.5.1 Cascadia Subduction Zone

The largest earthquakes affecting the Pacific Northwest have occurred along the Cascadia Subduction Zone where the Juan de Fuca plate dives beneath the North American plate. Some of the past earthquakes in the Cascadia Subduction Zone have had an estimated magnitude (M) as large as M 9.0 (Atwater and Hemphill-Haley, 1998, and Satake et al., 1996). These earthquakes have occurred, on average, about every 500 years, with the last earthquake occurring about 300 years ago. Earthquakes occurring in the Cascadia Subduction Zone would generally be located at least 60 miles (100 kilometers) west of the Route 9 site. Cascadia Subduction Zone earthquakes may produce ground shaking that lasts several minutes, which is much longer than shaking produced by earthquakes occurring in other source zones in the region.

2.5.2 Intraslab or Benioff Zone

Over the past 160 years, the largest earthquakes in the Puget Sound area all have originated within the subducting Juan de Fuca plate. These events are commonly called Intraslab or Benioff Zone earthquakes. These Intraslab or Benioff Zone earthquakes include the 1949 Olympia earthquake (M 7.1), the 1965 Seattle-Tacoma earthquake (M 6.5), and the 2001 Nisqually earthquake (M 6.8). Earthquakes occurring in this zone develop as a result of tensional forces in the down-dipping Juan de Fuca plate as it sinks into the mantle of the earth. This source zone is believed to be capable of producing earthquakes with magnitudes as large as M 7.5 (Frankel et al., 1996).

2.5.3 Crustal Zone

Most earthquakes in the Puget Sound region are produced in the Crustal Zone, which includes all earthquakes that occur within a depth of about 15 miles (25 kilometers) of the ground surface. The vast majority of these earthquakes are not associated with known faults.

A number of Crustal Zone faults have been identified in the Puget Sound area, including the SWIF, Seattle Fault, Tacoma Fault, Utsalady Fault, and the Devils Mountain Fault. These faults have been determined to be active and may be the source of future earthquakes. For instance, geologic evidence indicates that a large earthquake occurred on the Seattle Fault about 1,100 years ago, and the fault is believed to be capable of producing an earthquake with a magnitude as large as about M 7.0 to 7.5. Similarly, the SWIF is believed to be capable of producing an earthquake as large as M 7.3 (Johnson et al., 1996). The SWIF is the closest fault to the Route 9 treatment plant site. Compared to earthquakes originating on other more distant sources, large earthquakes on the SWIF would likely result in the strongest level of ground shaking on the Route 9 site.

2.6 What Is the Southern Whidbey Island Fault?

The SWIF is an active earthquake fault that crosses the southern end of Whidbey Island and extends in a southeasterly direction onto the mainland in southern Snohomish County. The SWIF has recently received the attention of the USGS in research studies to determine if active strands of the SWIF extend onto the mainland.

2.6.1 Location of the Southern Whidbey Island Fault

The SWIF has been postulated in varying locations by several researchers based on studies done over the past 20 years (Gower et al., 1985; Johnson et al., 1996 and 2001). These studies indicate that the SWIF is not a single fault trace; rather, it consists of multiple strands in a zone approximately 3 to 4 miles (5 to 6.5 km) wide (Johnson et al., 1996).

The location of the SWIF on Whidbey Island has been documented by various researchers (Johnson et al., 1996); however, up until about late 2003, it was only speculated that the SWIF extended onto the mainland in southern Snohomish County. Recent studies by the USGS (Blakely et al., 2004) provide evidence supporting the mainland extension of the SWIF, including a lineament of the SWIF (Lineament 4) that extends across the northern portion of the Route 9 site (Figure 2-3). More recent reinterpretations of the existing aeromagnetic data have led the USGS to postulate that another lineament (Lineament X) may cross the Route 9 site at the southern end of the site (Figure 2-3) (Sherrod et al., 2005).

2.6.2 Earthquakes on the Southern Whidbey Island Fault

Research suggests that the SWIF is capable of producing an earthquake with a magnitude as large as M 7.3 (Johnson et al., 1996) and that the fault ruptured as recently as 3,000 years ago causing approximately 3 to 6 feet (1 to 2 meters) of uplift of one salt marsh on Whidbey Island relative to another salt marsh (Kelsey et al., 2004). Research on liquefaction features in the Snohomish River delta was correlated to the occurrence of up to six earthquakes. At least one of the six earthquakes was correlated with an earthquake on the Seattle Fault, and the others are potentially related to earthquakes on the SWIF or other faults (Bourgeois and Johnson, 2001).

The USGS excavated trenches in locations of inferred mainland extensions of the SWIF in the summer and fall of 2004. Trenches were excavated in the vicinity of Crystal Lake, approximately 3 miles (5 km) east of the Route 9 site, and at the north end of the Route 9 site across Lineament 4 (Figure 2-3). Trenching results suggest that up to three separate earthquakes or ruptures have occurred on Lineament 4 of the SWIF since the end of the most recent glaciation, as shown in Table 2-1.

Evidence observed in the trenches excavated near Crystal Lake and at Lineament 4 reflect folding or warping of the ground surface, with only minor rupture on discrete fault planes in two locations. Geologic evidence from Whidbey Island and from trenches excavated across the Crystal Lake Lineament was interpreted by the USGS to indicate that at least four earthquakes were generated by the SWIF in the last 16,400 years (Sherrod et al., 2005). The USGS stated that as many as nine earthquakes could be attributed to the SWIF if all liquefaction features discovered in sediments of the Snohomish River delta are attributed to the SWIF.

Table 2-1. Inferred Earthquake Fault Movement on Lineament 4 of the Southern Whidbey Island Fault Since the End of the Most Recent Glaciation

Event	Years Before Present	Type of Movement	Vertical Movement (approximate feet/meters)
1	16,400 to ~12,000	Folding	>3 ft/>1 m
2	~12,000 to ~2,850 (Mid-Holocene)	Possible folding	Minimal <0.3 ft/<0.1 m
3	< 2,730	Faulting, folding, liquefaction	1 ft/0.3 m

Source: Sherrod et al., 2005

It is likely that earthquakes on the SWIF would include both vertical and horizontal displacement. Table 2-1 shows that the SWIF may be capable of producing vertical displacements of more than 3 feet (1 meter) during a large earthquake. Johnson et al. (1996) have interpreted the mechanism of the SWIF to include predominantly horizontal movement with some component of reverse faulting. However, the geologic data from the trenching of the SWIF are insufficient to characterize the amount or direction of horizontal movement that could occur.

For the purpose of evaluating potential environmental impacts in this Supplemental EIS, it is assumed that the SWIF may be capable of producing both vertical and horizontal movements of 3 to 6 feet (1 to 2 meters). Furthermore, because of the recent revelation of the extension of active strands of the SWIF onto the mainland, the analysis in this Supplemental EIS assumes that the SWIF would be capable of producing a maximum earthquake as large as M 7.5, which is somewhat larger than prior estimates of the maximum magnitude of M 7.3 (Johnson et al., 1996).

2.7 What Studies Have Been Done to Determine the Location of the Southern Whidbey Island Fault On and Near the Route 9 Site?

Seismic analysis for the Brightwater Regional Wastewater Treatment System has been done in stages and includes both regional and site-specific studies using several different methodologies. Studies have been carried out by the USGS, King County consultants, and other agencies. One goal of recent studies has been to determine whether or not an active fault is located on or near the Route 9 site.

2.7.1 Analyses Conducted for the Brightwater EIS

Chapter 4 of the Brightwater Final EIS evaluated the earth impacts of the Brightwater proposal based on information that was available prior to November 2003. It described the affected environment, regional earth conditions, seismicity, and mitigation measures for all EIS alternatives. It also described the extent to which the entire Puget Lowland has been subjected to seismic events in the past and is expected to be in the future, and it identified the postulated extension of the SWIF as being the nearest significant seismic feature to the Route 9 site.

The interpretations of regional and local geologic conditions, as presented in the Final EIS, were based on a review of geologic maps of the region, hydrogeologic reports, existing borings, and the results from borings and other explorations specifically advanced for the project. The USGS also was consulted regarding the results of their investigations of the SWIF.

The Final EIS also discussed the differing interpretations of the location of the SWIF that reflected the limited data available at the time the interpretations were made and discussed the more recent USGS data that had not been published at that time. The more recent USGS data suggested that the mainland extension of the SWIF could extend further to the south than thought by previous researchers.

Based on available information, King County concluded in the Final EIS that the only seismic impact to the Route 9 site would be potential liquefaction of some of the surficial soils. The Final EIS states that this impact could be mitigated by replacing the potentially liquefiable soils with densely compacted fill or by locating the structures on soils that are not susceptible to liquefaction. In addition, King County committed to working with the USGS to incorporate the latest information on the SWIF into the design of Brightwater facilities.

2.7.2 Aeromagnetic and Ground Magnetic Surveys

The USGS has conducted aeromagnetic surveys of the Puget Lowland as part of ongoing geological hazard investigations of the region. Based on these surveys, the USGS identified an aeromagnetic lineament at Cottage Lake, but no aeromagnetic lineaments were identified extending through the Route 9 site (Blakely et al., 2003). In March 2004, the USGS reinterpreted the existing aeromagnetic data for the region and compared the results with their review of the LiDAR data (see the discussion below). They identified a lineament from the LiDAR data (Lineament 4 as shown on Figure 2-3) that intercepted the northern end of the Route 9 plant site (Blakely et al., 2004).

After publication of the USGS Open-File Report 2004-1204 in April 2004 (Blakely et al., 2004), the USGS conducted ground magnetic surveys at the Route 9 site and also reassessed the existing aeromagnetic data. The recently released conclusions from this work (Sherrod et al., 2005) indicate the possible presence of another lineament (Lineament X) at the southern end of the site (Figure 2-3). Additionally, the recently acquired ground magnetic data indicate the presence of a discontinuous 240-foot-long (80-meter) lineament (Lineament GA in Sherrod et al., 2005) that is approximately parallel to Lineament 4 and located approximately 50 feet (15 meters) southwest of Trench 2a on the north end of the Route 9 site. The USGS believes this lineament is related to a fault. However, the data indicate that the lineament is not continuous; that is, the anomalous magnetic conditions defining the lineament do not appear to be present at either end of the 240-foot lineament, thus Lineament GA does not appear to continue beyond the mapped 240 feet.

2.7.3 LiDAR Surveys

The Puget Sound LiDAR Consortium gathers LiDAR (light detection and ranging imagery) data for the Puget Sound region. King County is a member of the Consortium, which also includes the City of Seattle, the Puget Sound Regional Council, the National Air and Space Administration (NASA), the USGS, the Kitsap Public Utility District, and Kitsap, Clallam, and Island Counties. King County funded the LiDAR flights over northern King County and southern Snohomish County. These flights were subsequently used by the Brightwater team (Appendix A) and the USGS (Blakely et al., 2003 and 2004) in evaluating the potential presence of faults related to the SWIF. Based on a reexamination of the LiDAR data in March 2004, the USGS identified a lineament (Lineament 4) at the north end of the Route 9 site that intersected the northeast corner of the existing StockPot Building (Figure 2-3). While a reexamination of the aeromagnetic data in the fall of 2004 led the USGS to postulate that another lineament (Lineament X) may cross the southern end of the Route 9 site (Figure 2-3), the extension of the lineament onto the Route 9 site could not be confirmed with the LiDAR data.

2.7.4 Reevaluation of Soil Samples on the Route 9 Site

In response to the USGS identification of LiDAR Lineament 4 at the north end of the Route 9 treatment plant site (Blakely et al., 2004), King County conducted additional studies in April 2004, including a reevaluation of soil samples from borings drilled earlier at the Route 9 site, to assess the potential presence of features that may be related to the SWIF. Specifically, the samples were reviewed to determine whether there was evidence that could suggest potential earthquake faulting, such as fractures, zones of disturbance, and offset beds or locations where similar soil units or marker beds were encountered at differing elevations in adjacent borings.

The studies primarily focused on the samples retrieved from Boring PB-12, the deepest of the plant site explorations, which was drilled to a depth of 501 feet (153 meters) near the south end of the site (Figure 2-3). The log for Boring PB-12 showed some local zones of disturbance in glacially overridden soils below a depth of 200 feet (60 meters). The features that were observed were subtle and typically consisted of small (less than 1-inch-wide) sand or clay-filled cracks within hard clayey silt. The subtle features observed in the samples were typical of glacially induced deformation and are not exclusively associated with other features of active faulting (King County, 2004a).

2.7.5 Seismic Refraction Survey

King County conducted seismic refraction surveys on the Route 9 site in April 2004 to investigate the subsurface soils for indications of a subsurface fault (King County, 2004b). Surveys were conducted along two lines southwest of the StockPot property and along nine lines at the north end of the site in the vicinity of Lineament 4.

The results of the survey revealed locally high shear wave velocities at one location, but the high velocities were not observed in a pattern that would suggest faulting. Thus the results of the seismic refraction survey were inconclusive regarding the presence or absence of a fault at the north end of the Route 9 site.

2.7.6 Soil Borings Across Lineament 4

In August 2004, twelve soil borings were drilled across the projected trace of Lineament 4 at the north end of the Route 9 site. The purpose of these explorations was to investigate the types and consistency of soils located on either side of Lineament 4 in an effort to refine the potential location of any subsurface faulting. Nine of the borings were located along a 700-foot-long (214-meter) line oriented roughly perpendicular to the projection of Lineament 4; the other three borings were located along a 100-foot long (31-meter) line approximately 200 feet (61 meters) to the east.

These explorations extended from 15 to 40 feet (5 to 12 meters) below the existing ground surface. Soil samples were obtained at closely spaced intervals during the drilling of each boring. An engineering geologist logged the type and consistency of each soil sample as it was recovered. The groundwater depth was observed during drilling and from water level measurements in piezometers installed as part of the exploration program.

Information from the explorations was used to develop detailed soil cross-sections of Lineament 4. These cross-sections show the location of the top of each soil unit. Information from the cross-sections was used to refine the interpretation of seismic refraction surveys, the planning for the excavation of trenches across Lineament 4, and the interpretation of the trench geology.

Details of the exploration program, including logs of each soil boring and the soil cross-sections developed from these borings, were summarized in a data report (Aspect Consulting, 2005).

2.7.7 Geologic Reconnaissance

Aided by the findings of the aeromagnetic and LiDAR surveys, scientists and engineers from the Brightwater design team and the USGS performed a reconnaissance of portions of the Route 9 site in August 2004 to look for evidence of potential surface expressions of underlying faults. The most prominent surface expression observed was a slight (up to about 1 foot or 0.5 meter) elevation differential in the ground surface at the north end of the site, which corresponded approximately to the location of Lineament 4 in the USGS Open-File Report 2004-1204 (Blakely et al., 2004). Another topographic feature was observed near the inferred alignment of Lineament 4 on King County property east of the railroad tracks and east of the proposed Brightwater facilities. Both of these features were selected for trenching to further evaluate the potential presence of subsurface faulting.

2.7.8 Excavation and Analysis of Trenches Near Lineament 4

The USGS used data from the aeromagnetic surveys, the LiDAR surveys, the soil borings, and the geologic reconnaissance to determine the best locations for excavating trenches on or near Lineament 4. Two trenches were excavated near Lineament 4 in September 2004 (Trench 2a and Trench 2b in Figure 2-3). The purpose of the trenching was to evaluate whether the surface expressions indicated by the LiDAR data were underlain by deformed or offset soil beds that could be caused by fault movement. Examination of Trench 2a, at the northern end of the Route 9 site, indicated the presence of ground deformation or folding that is most readily explained by earthquake faulting. Trench 2b exposed zones of deformation and disturbance; however, the observed deformation was in deposits that had been overridden by glacial ice more than 16,400 years ago and therefore was not clearly the result of recent tectonic activity that could be used to interpret the presence of active earthquake faults.

The mapping of Trench 2a (Appendix A) suggested ground deformation or the occurrence of earthquakes on at least two and possibly three occasions (Table 2-1). The oldest movement occurred about 16,400 to 12,000 years ago and reflects more than 3 feet (1 meter) of uplift or warping of the ground. This warping was generally constrained within a horizontal distance of about 30 feet (10 meters). The second possible event occurred in the early to mid-Holocene (after about 12,000 years ago and before about 2,850 years ago) and is associated with minimal ground deformation. The third event occurred no more than about 2,730 years ago and is expressed as settlement of a wetland soil deposit of about 1 foot (0.3 meter). In summary, data from Trench 2a on Lineament 4 demonstrate that the lineament is an active fault that has experienced earthquake movement on at least two and possibly three occasions (Appendix A).

2.7.9 USGS Interpretations of Data

The USGS has recently conducted research on the mainland extension of the SWIF and has released two Open-File Reports of its findings (Blakely et al., 2004, and Sherrod et al., 2005). The reports discuss USGS interpretations of aeromagnetic and LiDAR data in south Snohomish County and north King County that identify lineaments that could potentially be related to fault strands of the SWIF.

The report released in spring 2005 (Sherrod et al., 2005) includes the results of trenching the Cottage Lake lineament of the SWIF at Crystal Lake and trenching Lineament 4 at the northern end of the Route 9 site. The report includes interpretations of the aeromagnetic data that indicate the presence of a lineament (Lineament X) that may cross the southern end of the Route 9 site. The report also includes a ground magnetic survey in the vicinity of Trench 2a on the north end of the Route 9 site. The recently acquired ground magnetic data indicate the presence of a discontinuous 240-foot-long (80-meter) lineament (Lineament GA in Sherrod et al., 2005) that is approximately parallel to Lineament 4 and located approximately 50 feet (15 meters) southwest of Trench 2a. The USGS believes this lineament is related to a fault. However, the data indicate that the lineament is not continuous; that is, the anomalous magnetic conditions defining the lineament do not appear to be present at either end of the 240-foot lineament, thus Lineament GA does not appear to continue beyond the mapped 240 feet.

2.8 What Can Be Inferred About Seismic Features On or Near the Route 9 Site?

Multiple lines of investigation were used to evaluate the presence of earthquake faults at the proposed Route 9 Brightwater Treatment Plant site. These methods confirmed the presence of an active fault, Lineament 4, beneath the northern end of the site. An aeromagnetic lineament, referred to as Lineament X, was identified crossing the southern end of the site. The location of Lineament X also is correlated with a linear drainage channel west of the site. However, the presence or absence of Lineament X on the Route 9 site cannot be confirmed with existing LiDAR data. Finally, neither the existing aeromagnetic data nor the LiDAR data suggest the potential presence of faults between Lineaments 4 and X.

In addition, the analysis of the evidence at the Route 9 site suggests the following:

- Lineament 4 is an active strand or fault of the SWIF that has produced movement and earthquakes on two and possibly three occasions within the past 16,400 years. The most recent movement is inferred to have occurred no more than about 2,730 years ago.
- The more than 3 feet of ground deformation observed in Trench 2a is consistent with inferred movement of the SWIF on Whidbey Island; these movements also are consistent with the occurrence of a M 6.5 to 7.0 earthquake (Sherrod et al., 2005).
- An earthquake on Lineament 4 or X may produce ground shaking at the Route 9 treatment plant site with a peak ground acceleration of about 0.65 g (Appendix B). The saturated loose-to-medium-dense granular alluvial soils in the mitigation area at the north end of the treatment plant site could liquefy under this level of ground shaking. However, no new process structures are proposed in the mitigation area. Liquefaction is not expected beneath the new treatment plant structures because they will be founded on glacially consolidated sediments or compacted fills that are not susceptible to liquefaction.
- The ground deformations observed in Trench 2a at Lineament 4 consist of folding or warping of the ground surface as opposed to a rupture along a defined fault

plane. An earthquake occurring about 16,400 to 12,000 years ago produced the greatest vertical ground deformation observed in the trench of about 3 feet (1 meter) or more. Vertical deformations from subsequent earthquakes were estimated to be less than 1 foot (0.3 meter). In the future, this type of deformation may occur over a distance of about 30 feet (10 meters) from the fault. Based on past deformations observed in the trenches, a rupture or tear in the ground surface is not expected, but could occur.

- The LiDAR data are not sufficient to substantiate or refute the aeromagnetic interpretation of Lineament X at the south end of the Route 9 site. Thus, while it is possible that Lineament X may be a fault, the data do not suggest it is an active fault with the same degree of development as that observed at Lineament 4. However, for purposes of design and this Supplemental EIS, King County is treating Lineament X as an active fault.
- Lineament GA, recently identified by the USGS (Sherrod et al., 2005), lies approximately 50 feet (15 meters) southwest of Trench 2a and runs parallel to Lineament 4. While the USGS believes the lineament is related to a fault, Lineament GA is not a major structure because the ground magnetic data show that the lineament is only 240 feet (80 meters) long, and the data do not show the lineament extending further into the plant site area. It is unclear how Lineament GA relates to features observed in Trench 2a, particularly when considering that the western half of Trench 2a, adjacent to Lineament GA, shows no indication of faulting. Hence, it appears that Lineament GA is not a major structure and only a minor or secondary feature related to Lineament 4.
- A ground rupture between Lineaments 4 and X is not expected nor is it supported in the existing aeromagnetic and LiDAR data between these two lineaments. However, this lack of evidence is not conclusive proof that additional faults are not present on this part of the site. Consequently, for purposes of this Supplemental EIS, King County is addressing a worst-case scenario that assumes the presence of an active fault between Lineaments 4 and X.

2.9 What Uncertainties Remain About Seismic Features On or Near the Route 9 Site?

Several studies have been conducted to determine more precisely the location of the SWIF and any lineaments that may be present on or near the Route 9 site. Nevertheless, there is still a level of uncertainty about the precise location and possible future movement of the SWIF and its lineaments. Seismology and earthquake engineering have not evolved to a state allowing reliable predictions of the date, specific location, and magnitude of future earthquakes. Predictions of earthquake hazard are based on an assessment of historical records and on geologic data on past earthquakes. Therefore, there is always a level of uncertainty, not only in the observed data but also in the applicability of past events, which in turn brings inherent uncertainty to the modeling of future earthquakes. Potential areas of uncertainty include (1) the precise location of faults, (2) whether an earthquake will occur, (3) the likelihood of an earthquake occurring during the 50-year design life of the Brightwater Treatment Plant, and (4) if an earthquake were to occur, where and when it would occur and how severe it would be.

2.9.1 Whether an Earthquake Will Occur in the Puget Sound Region During the Design Life of the Brightwater Treatment Plant

Earthquakes have been reported on numerous occasions in the Puget Sound region over the past 160 years. This well-documented seismic history suggests that the region will experience ground shaking from a strong earthquake at least once during the design life of the Brightwater Treatment Plant proposed at the Route 9 site. Based on the historical earthquake record in the region and the current understanding of mechanisms that cause earthquakes in the area, it is quite likely (greater than 50 percent probability) that the treatment plant and conveyance system will experience ground shaking from a large earthquake, M 6.0 or greater, occurring somewhere in the Puget Sound region during the next 50 years. Support for this forecast includes the occurrence of the three largest historical earthquakes in the region: the 1949 Olympia Earthquake (M 7.1), the 1965 Seattle-Tacoma Earthquake (M 6.5), and the 2001 Nisqually Earthquake (M 6.8). All three of these events occurred more than 30 miles (48 km) below the surface and more than 25 miles (40 km) from the Route 9 site. They did not occur on the SWIF, nor were they accompanied by ground surface rupture. The historical earthquake record of the region suggests that it is highly unlikely that an earthquake would occur on Lineament 4 or X of the SWIF during the expected 50-year design life of the treatment plant.

2.9.2 Possible Faults on the Route 9 Site

Multiple lines of investigation, including aeromagnetic surveys, LiDAR surveys, seismic refraction surveys, borings, geologic reconnaissance, and field trenching, were used to evaluate whether earthquake faults are present at the Route 9 site. These methods confirmed the presence of an active fault (Lineament 4) beneath the northern portion of the site (Blakely et al., 2004). Researchers concluded that Lineament 4 has generated earthquakes on at least two and possibly three occasions (Appendix A).

While an aeromagnetic lineament, referred to as Lineament X, was identified crossing the southern portion of the site, the existing data are insufficient to confirm whether this lineament is underlain by a fault. On the assumption that the lineament is a fault, it could potentially provide a zone of weakness where movement could occur during a future earthquake. However, there is no direct evidence indicating that Lineament X is an active fault.

Finally, none of the available information suggests the potential presence of faults between Lineaments 4 and X.

2.9.3 Magnitude of an Earthquake Affecting the Route 9 Site

Just as there is uncertainty about whether an earthquake would occur that would affect the Route 9 site during the design life of the Brightwater Treatment Plant, there also is uncertainty as to the magnitude of an earthquake if one were to occur. While the three largest earthquakes in the Puget Sound region in the past 60 years have had magnitudes ranging from M 6.5 to 7.1, it is much more common for the region to experience smaller earthquakes (less than M 5.0) that cause minimal or minor damage to engineered structures. If an earthquake were to occur affecting the Route 9 site, ground shaking would occur. The level of ground shaking most likely would not be severe, and it is highly unlikely that a surface rupture would occur on the site.

Johnson et al. (1996) estimated that the SWIF may be capable of producing an earthquake as large as M 7.3. However, the results of recent research that concludes that active strands of the SWIF extend onto the mainland (Blakely et al., 2004, and Sherrod et al., 2005) would suggest that the SWIF may be capable of generating a larger earthquake because of its recently inferred greater fault length. Accordingly, the analysis in this Supplemental EIS assumes that the SWIF would be capable of generating an earthquake as large as M 7.5. While the length and the amount of past movement of the SWIF may not be precisely known, potential variances in these parameters may amount to a few tenths difference in the estimated maximum magnitude of future earthquakes from the value cited above. Such variations were considered in the probabilistic seismic hazard analysis prepared for the Route 9 site (Appendix B).

2.9.4 Potential for Fault Movement or Ground Rupture on the Route 9 Site

Lineament 4 has been confirmed as an active fault on the Route 9 site. While there is likely to be movement on the fault at some time in the future, it is impossible to predict with certainty whether the movement would result in a rupture of the ground surface or cause only shaking. Lineament X has not been confirmed as being a fault, and there is no evidence to suggest that another fault lies between Lineaments 4 and X. Consequently, it is unlikely that earthquake faulting would rupture the ground surface along Lineament X or between Lineaments 4 and X. Nevertheless, rupture of the ground surface along Lineament X or in the area between Lineaments 4 and X at some time in the future cannot be absolutely ruled out.

The studies of Trench 2a at the north end of the Route 9 site detected two or three occurrences of fault-related ground deformation over the past 16,400 years (Table 2-1). These observations yield an average interval of as much as 9,000 years to as little as 4,000 years between the earthquakes. The most recent earthquake interpreted in Trench 2a occurred more recently than 2,730 years ago (Sherrod et al., 2005). As such, ground deformation or faulting on Lineament 4 would have about a 1 percent probability of occurrence during an assumed 50-year design life of the plant (Figure 2-4). Stated differently, Lineament 4 may move once during 100 life spans of the treatment plant facility. Also, the average interval of earthquake movements of Lineament 4 is about 50 times longer than the conventional design practice for a 100-year flood or storm, so the probability of occurrence of movement of Lineament 4 is extremely remote when compared to other natural events. Furthermore, features similar to those along Lineament 4 are not found at Lineament X or between Lineaments 4 and X on the Route 9 site; this would suggest an even lower probability of fault deformation in those locations.

Because it is impossible to predict with absolute certainty whether or precisely where a rupture of the ground surface could occur on the Route 9 site, King County has made a hypothetical worst-case assumption in this Supplemental EIS that a fault rupture could occur anywhere on the Route 9 site. The analysis of environmental impacts reflects this worst-case assumption, consistent with the SEPA Rules (WAC 197-11-080) (see Chapters 4 and 5).

2.9.5 Potential for Ground Shaking on the Route 9 Site

The estimated amount of ground shaking that potentially could occur on the Route 9 site during an earthquake is being taken into account in the design of the Brightwater Treatment Plant and the conveyance system. All facilities are being designed to meet or exceed the seismic design standards of the 2003 International Building Code (see Chapter 3).

The method used to estimate the level of ground shaking that could occur on the Route 9 site was based on observations of ground shaking from past earthquakes in differing geologic and tectonic environments and on studies of mechanisms that could cause ground shaking. These empirical equations and models of the earthquake source mechanisms have a level of uncertainty reflecting the range of the data from the empirical observations and the fundamental understanding of the seismic source mechanisms. While an empirical relationship or seismic source model may be used to predict ground motion that would be caused by a future earthquake, these predictions may underestimate or overestimate the severity of ground shaking that could occur. An effort was made to account for this uncertainty in the probabilistic seismic hazard analysis prepared for the Brightwater project (Appendix B); however, the possibility exists that the allowances for uncertainty will be exceeded. This possibility is expected to be small.

While there are uncertainties in the prediction of ground motions, recent earthquakes in the Seattle area have produced much lower ground motions than those being used for the design of the Brightwater facilities. This suggests that the ground motion values being used for the design of Brightwater facilities are very conservative. For example, the three largest earthquakes in the Puget Sound region (the 1949 Olympia Earthquake, the 1965 Seattle-Tacoma Earthquake, and the 2001 Nisqually Earthquake) all resulted in relatively minor levels (about 0.15 g) of ground shaking at the Route 9 site and along the alignment of the conveyance tunnel. Brightwater facilities are being designed to withstand ground shaking of 0.65 g. This level is approximately 25 percent greater than the 0.51g currently specified in the seismic hazard maps for the Route 9 site in the 2003 International Building Code (IBC 2003), which is the governing code for design of all structures in the State of Washington and Snohomish County (see Chapter 3). The 0.65 g design acceleration also is about four times greater than historical ground shaking estimated to have occurred on the Route 9 site in the past 160 years. The high level of ground shaking assumed at the Route 9 site reflects the potential occurrence of earthquakes on Lineaments 4 and X, whereas the IBC 2003 does not recognize the mainland extension of the SWIF.

2.9.6 Earthquake Damage to Public Services

During a strong earthquake, damage to public facilities and services, such as highways, bridges, and the water supply, could occur. While this damage would not be directly related to or caused by the Brightwater System, damages to public services could potentially delay the repair and recovery of the Brightwater Regional Wastewater Treatment System.

The uncertainties surrounding damage to public services during a strong earthquake include the degree of damage, the length of emergency response time, and the length of recovery time before public services could be provided again. Generally, the road system would be the limiting factor for delivery to the Brightwater site of emergency services such as fire and medical response and delivery of equipment and services for repair (see Chapter 4). Even if utilities such as electricity, natural gas, and water that serve the Brightwater Treatment Plant were to survive the earthquake or were quickly repaired, equipment, materials, and personnel still would need to use the road system to reach the Route 9 site. If the primary roads to the plant were out of service, alternative routes and/or transportation methods would need to be used for delivery.

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